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**NAVAL AIR SYSTEMS COMMAND  
FUELS & LUBRICANTS DIVISION  
AIR-4.4.5**

*Research Report*

**STUDY OF BRAYCO CORROSION  
INHIBITOR ADDITIVE IN MIL-PRF-23699  
CLASS C/I TURBINE OIL**

**NAVAIRSYSCOM REPORT 445/02-003**

**2 August 2002**

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## **STUDY OF BRAYCO CORROSION INHIBITOR ADDITIVE IN MIL-PRF-23699 CLASS C/I TURBINE OIL**

### **FINAL REPORT**

#### **1. Background**

Tinker AFB is responsible for the overhaul of Navy F110-GE-400 and Air Force F110-GE-100 engines. Maintenance personnel noticed an increase in corrosion pitting of accessory gearbox and some mainshaft bearings in Air Force F110-GE-100's. General Electric (GE), the engine manufacturer, suggested using MIL-PRF-23699 Class Corrosion Inhibiting (CI) vice MIL-PRF-7808. They then recommended adding Brayco 599, an aftermarket corrosion inhibitor, to the oil at a 7% concentration before the test cell verification run. GE currently uses this process at the factory with both commercial and military engines. In June 2000, AIR-4.4.5, the qualifying agency for MIL-PRF-23699 gas turbine engine oil, received a call from the F110 In-Service Engineer (ISE) concerning the use Brayco 599 in Navy engines. The Navy rescinded the instruction requiring the use of Brayco 599 in standard MIL-PRF-23699 several years ago because it was never proven to have an effect on reducing bearing corrosion rates. Contributing to this decision was its lack of use by maintenance personnel and its ineffectiveness as a long term preservative due to its volatility. This prompted the development and introduction of MIL-PRF-23699 Class CI. This oil is the current 'green' can oil and is used by Tinker AFB to service the F110. Because the effects of introducing an external CI additive were unknown, a study was initiated by AIR-4.4.5 to assess the physical and chemical properties of the oil blended with Brayco 599.

This report only considers the performance of blended oils composed of Brayco 599 corrosion preventative additive mixed into MIL-PRF-23699 CI lubricant. Use of Brayco 599 at various concentrations and with other type lubricating oils should be evaluated by the using authority.

#### **2. Method of Test**

Several samples were blended up for testing. Brayco 599 was mixed with a recent production batch of MIL-PRF-23699 Class CI oil in the following ratios: 1.25%, 2.5%, 5%, 7% and 10%. Several MIL-PRF-23699F specification and non-specification laboratory and bench tests were performed to assess various properties of the blends and are described below:

a. Viscosity and Total Acid Number (TAN) testing was done to determine the basic physical properties of the oil.

b. Sediment testing was performed to determine the amount of particulate in the oil. The sample was filtered through a 1.2 micron pore size filter and the filter weighed to determine the amount of sediment present.

c. Compatibility testing was performed by placing the blends in the oven at 93.5°C (200°F) for 7 days. They were then filtered to determine if the elevated temperature had initiated a reaction between additives.

d. Low temperature storage stability testing was performed to determine the oils' reaction to extended cold periods. The test is run at -18°C (0°F) for 6 weeks after which the oils are checked for sediment, separation or gelling.

e. Foam testing was done to determine the propensity of oil to foam under certain test conditions. Foaming can cause fluctuations in oil pressure and a reduction in lubrication characteristics. Testing was performed on various blended oils at 93.5°C (200°F), for Sequence II, and after cooling from 93.5°C to 24°C (75°F), Sequence III.

f. Elastomer compatibility testing was performed to determine the effect of the blends on nitrile and fluorocarbon elastomers. The test was performed using materials indicative of those seen in engine or gearbox O-rings and is run at 70°C (158°F) for nitrile rubber and 204°C (400°F) for fluorocarbon rubber for 72 hours. The elastomers were checked for excessive swell at the conclusion of the test.

g. Trace metal content was performed to verify that the Brayco 599 additive was not contributing to an increase in elemental content. The test was run on an emission spectrometer similar to that used in the fleet.

h. Oxidation/Corrosion testing was performed to assess oxidative stability and resistance to metal attack at higher temperatures. The test simulates bulk oil conditions in the presence of specific metals that act as catalysts. This test was run at 204°C for 72 hours with coupons of steel, silver, copper, magnesium and aluminum. At the conclusion of the test, the oils' physical properties are evaluated and the metals inspected and weighed.

i. Thermal Stability/Corrosivity testing was performed to determine resistance to metal attack under different conditions than those seen in Oxidation/Corrosion testing. Here, the test is used to simulate conditions seen in an oxygen-deprived environment. In this environment, metal attack can occur beneath the oil deposits. The test was run at 274°C (525°F) for 96 hours and at the conclusion of the test, oil properties and degree of metal attack are determined.

j. Ball Corrosion Testing (BCT) was performed to determine the oil's corrosion inhibiting properties. Test specimens are placed in a humidity chamber and subjected to temperature cycling from 5°C (40°F) to 40°C (104°F) over the course of 7 days. The specimens are removed and checked for any sign of corrosion, indicating failure. Passing the test requires that 75% of the specimens be corrosion free.

k. 4-Ball testing is used to determine the relative wear preventative properties of lubricants under certain test conditions. Three 0.5 inch 52100 steel balls are clamped together in a

specimen holder then submerged in the test fluid. The holder is loaded against a fourth ball that is mounted to a spindle and rotated at 1200 rpm for one hour at 74°C. Wear scar measurements at the contact surfaces are made after each test. Smaller wear scar diameters are indicative of better anti-wear protection. The testing was performed at loads of 10 and 40 kilograms.

l. The Ryder Gear Test is used to determine load carrying capacity of MIL-PRF-23699 and DOD-L-85734 lubricants. Oil performance is measured against an unadditized basestock reference fluid with a known historical score in the Ryder Test. Oil performance is a function of its ability to maintain an oil film thickness in the gear mesh under load as well as its ability to plate additives onto the gear surfaces to provide anti-wear protection during the onset of scuffing as the film thickness disappears under successive higher loading. MIL-L-23699 oils must show at least a marginal improvement (102% minimum) relative to the reference oil at a test oil temperature of 165°F (74°C) and a test speed of 10,000 rpm. This can be achieved by adding a phosphorus-based anti-wear (or load carrying) additive. However, in many cases anti-wear additives must vie for the surfaces of the Ryder gear teeth in conjunction with corrosion inhibiting additives or chemistries that promote high thermally stable oils. The Ryder Gear test has proven to be adept in determining whether such oil formulations are able to maintain anti-wear protection.

During a Ryder test, the test gears are initially loaded at a "10 lb" load oil pressure for a ten minute run, and then at successively increasing increments of 10 lbs thereafter (to a maximum load stage of 100 lbs). At the end of each loading period, the test is stopped and each portion of the narrow test gear is examined to determine the percent of the tooth area scuffed. An oil fails the Ryder Gear test when the average gear tooth scuffing on the narrow gear progresses to an average of 22.5% over the 28 gear teeth. The 22.5% average percent of tooth area scuffed is then determined from a plotted curve. The oil's "load carrying capacity" can then be calculated, and rated relative to the reference basestock oil's measured performance in the test.

m. 4-Ball Extreme Pressure (EP) testing is used to determine the load carrying properties of a lubricant under severe conditions. The test set-up is the same as described in paragraph k. above. The test duration is 10 seconds at increasing loads until catastrophic failure (welding) of the test specimens occurs. The weld load and Load Wear Index is then determined. The Load Wear Index was determined for each sample. The lower the index, the larger the wear scars on the test specimens at each successive load.

n. AIR 4.4.5 evaluated several blends in a developmental test method known as the "WAM High Speed Load Carrying Capacity Test", which has been developed by Wedeven Associates Inc., of Edgemont PA, under Navy contract. AIR 4.4.5 promotes the development of this method due to its ability to characterize an oil's traction behavior, which reflects its lubricating attributes of preserving gear-type topographical surface features under simulated gear contact conditions. Under successive step-loading, the test method also leads to a failure event which simulates gear tooth scuffing damage which is an attribute traditionally measured by the U.S. Navy Ryder Gear Test.

o. Aviation Lubricant Tribology Evaluator (ALTE) testing was done on the neat MIL-PRF-23699 CI oil and blends of 1.25% and 7%. It consists of a vertically mounted non-rotating ball forced against an axially mounted cylinder under applied load. The cylinder is rotated at a fixed speed while partially immersed in the test oil. The "scuffing wear" test conditions are 220 rpm for 1 minute with the test oil at 150°C. Both conditions use 4 kg load steps. Failure criteria is a 1.5mm wear scar on the rotating cylinder.

p. High Temperature Deposition (HTDT) Testing was performed on selected samples. This test was designed to simulate scavenge line coking experienced in some aircraft engines. In this test, an air/oil mixture flows over a steel tube with a temperature profile ranging from 290°C to 360°C. Test duration is 15 hours. At the end of the test, the tube is weighed and a numerical system is used for obtaining an overall rating of the deposition characteristics of oil. Oil consumption, filter deposits (if any), viscosity change and TAN change are measured and recorded.

q. The Vapor Phase Coker (VPC) test attempts to simulate the conditions seen in bearing vent tubes and is used to evaluate the propensity of the lubricants under test to form carbonaceous deposits. In operation, air is fed through one neck of a flask containing the test oil, creating an air-oil mist. This mist is then permitted to escape through a controlled temperature furnace then directly into a stainless steel tube, where the mists condense and deposits are formed. The tube is instrumented with six thermocouples along its length. At the end of the test, the tube is weighed to measure deposit build up. It is then cut in half and the lower, upper and maximum deposit locations are measured. The deposit locations are compared to the temperature profile obtained during the test and the deposit formation temperatures are ascertained. In addition, oil consumption and viscosity change is measured.

### 3. Discussion of Results.

The results in Table 1 show the laboratory test results of the various concentrations of Brayco 599 in MIL-PRF-23699 Class C/I.

a. The results for viscosity increase as the concentration of Brayco 599 increases, which is understandable due to the higher viscosity of the Brayco, 41.1 centistokes (cSt) versus 25.72 cSt for the neat oil. The Total Acid Number (TAN) also increases with higher concentrations of Brayco. This is due to the very high TAN of the Brayco and can be attributed to the corrosion inhibitor additive. This increase in itself should not cause a detrimental effect to the engine or its components.

b. The sediment test was performed after blending the oils at room temperature then filtering. The results did not indicate any adverse reaction between the Brayco 599 and the CI oil.

c. Heating the samples in the oven for 7 days for the compatibility test did cause an increase in the amount of sediment formed. In all concentrations except 2.5%, the amount of sediment

was greater than that of the neat oil. These results show that there is some degree of incompatibility between the Brayco and CI oil. However, the results are not overly excessive.

d. Low temperature storage stability results show no separation or gelling of any of the samples, indicating good miscibility between the Brayco 599 and the neat oil.

e. Elastomer test results show the Brayco additive to have very little if any effect on nitrile or fluorocarbon compounds when compared to the neat oil. This indicates good seal compatibility.

f. Foam testing of the 10% concentration was performed as a worse case scenario. The sample passed specification requirements for new oil, indicating the Brayco 599 does not promote foaming under these conditions.

g. Trace metal analysis of the neat CI oil, various concentrations and the Brayco 599 itself were determined. The Brayco was found to have more iron and phosphorous than the neat oil, which is most likely due to the additive package. This contributed to the 1 ppm of iron and increasing phosphorous seen in the various blended samples.

h. Oxidation/Corrosion testing was performed on the neat CI oil, 1.25%, 7% and 10% blends. Viscosity change results for the neat oil and 1.25% sample were virtually identical, as would be expected due to the low concentration of Brayco. The viscosity changes for the other samples showed a slight decrease as the concentration increased. This is most likely due to the higher pre-test viscosity of the blends. TAN change for the 7% and 10% concentrations actually showed a decrease. Usually, oil that is thermally stressed shows increases in both viscosity and TAN. The fact that TAN decreased shows that certain acids in the Brayco are volatile and evaporate when heated, lowering the TAN. Contamination values for the blended samples increased from those seen with the neat oil. However, these values are not overly excessive. Metal weight change determined for the various samples was also acceptable.

i. Thermal Stability/Corrosivity testing showed a decrease in viscosity and an increase in TAN. This is due to the breakdown of the polyglycols, used to increase viscosity, in the Brayco 599. Some of these longer chain molecules are also in turbine oil. These long chain glycols can break down into shorter chains under high temp conditions, lowering viscosity. This effect is also seen in neat turbine oil.

j. Ball corrosion testing was done on the unused samples of neat oil, 1.25% and 7% concentrations. The 7% blend was also tested after Oxidation/Corrosion testing to determine its properties after being thermally degraded. All samples passed the test, indicating that the Brayco 599 does not interfere with the corrosion inhibiting properties of the neat CI oil. A light film was seen on the Brayco concentration post-test specimens.

k. 4-Ball testing was performed on the neat oil as well as all blends. Wear scar diameters for the blended oils were similar to those seen with the neat oil, given the accuracy of the test.

l. Ryder gear test results indicate that the Brayco 599 additive has a detrimental effect on load carrying when used with the MIL-PRF-23699 C/I oil. While the specification limit is 102%, the result for the 7% blend was 93% of the relative rating achieved by the reference oil. The results for a production batch of the neat CI oil were 110%, indicating the additive caused a 15% drop in load carrying capacity. This is not surprising considering antiwear and corrosion additives are surface active and compete for the same surfaces. Unfortunately, Ryder performance at this level can cause premature wear in the bearing and gear systems (of engines, accessory gearboxes, GTC's, AMAD's, etc.) in marginally lubricated contacts.

m. 4-Ball EP testing was performed on the neat oil sample, 1.25% and 10% Brayco concentration samples. The 10% Brayco concentration sample had significantly lower Load Wear Index than the neat and 1.25% concentration sample, indicating a decrease in antiwear properties. In this test, the film thickness is unable protect the surfaces due to the much higher test loads.

n. WAM testing was performed on a selected MIL-PRF-23699 CI oil with and without the Brayco 599 in this test. As loading increases, the resulting traction coefficient curve is plotted for each sample as an average of four tests. As seen in Figure 1, the initial rising traction coefficients indicate the oil is protecting the surface features of the test specimens. Declining values are signaling wear or polishing of the specimens, while a steep drop indicates microscuffing. The upward arrows located on the traction curves indicate the average load stage at which a scuffing event occurs for each oil, and signals a potential correlation to the U.S. Navy Ryder Gear Test. In Figure 1, it can be seen that the oil with the Brayco 599 (coded PE-5-L2058) suffers a distinct reduction in both anti-wear and scuffing performance when compared to the neat oil (coded PE-5-L2002). Such reductions in performance have been known to cause unacceptable performance in the U.S. Navy Ryder Gear Test and therefore, would not be qualified to the specification. Oils with similar profiles have been removed from service because they generated excessive wear.

o. The ALTE test results are shown in Figure 2. The oils tested included a reference fluid, the neat CI oil and the CI oil with 7% Brayco 599. The results show nearly identical performance between the neat and blended oils within the repeatability of the test.

p. As can be seen from the HTDT results in Table 2 and Figures 3-5, the addition of the Brayco additive is detrimental to the selected CI oil formulation at the 7% and 10% mixtures. Within the repeatability of the HTDT test, the addition of 1.25% Brayco additive into the CI oil formulation does not seem to have a major affect on the typical results. The tube deposit weights are within the expected results for this oil. The deposit, as measured by the Deposit Type Rating, is slightly more severe than what is typically seen. The viscosity change is in the same range as the neat oil. The TAN change appears to be different, but the addition of the Brayco additive increases the new oil TAN value by 0.3 mg KOH/g. Removing this difference from the starting point, leaves a TAN change for the 1.25% blended oils slightly lower than the CI oil.

One aspect of the 1.25% Brayco mixture which appears different from the typical neat oil performance is the rate of deposition occurring on the test tube during the test. The HTDT has

air-oil slug flow on the outside of the stainless steel test tube. On the inside of the test tube there are four thermocouples which measure the interior wall temperature. As deposits form on the outside of the tube, an increase in temperature occurs from the insulating properties of deposits. In Figure 3, it can be seen that the CI oil by itself does not exhibit a rapid increase in temperature with time in all six tests. (Test 2072 does have a slow increase with time for the TopMid measurement.) The HTDT tests with 1.25% Brayco (Figure 4) show a slight but steady increase with time for all three tests performed at the "TopMid" thermocouple location.

Figure 5 shows the temperature plots with time for the 7% and 10% Brayco mixtures. All the tests show a measured rise in temperature with time. Three of the four tests performed have exponential increases in deposit build up at the end of the test. Clearly the oil's performance has been compromised with the larger doses of the Brayco additive. This data is reflected in the tube deposit weight measurements found for the 7% and 10% mixtures in Table 2. With the exception of one of the four tests, the viscosity and acid number changes are more severe than typical neat oil performance.

These plots indicate that not only do the 7% and 10% blends cause more deposits, but they also form them in a shorter period of time. The consequence of this early deposit formation is that the engines will become dirtier after operating for less time.

q. Vapor Phase Coker Tests (VPC) were performed on three different blends of neat CI oil and Brayco 599. The Brayco additive was blended into the neat oil at 1.25%, 7% and a 10% solution. In addition, VPC tests were performed on the neat oil for a comparative baseline.

As shown in Figure 6, the various blends of Brayco contaminated oil did not significantly change the tube deposits weights when compared against the CI oil formulation. However, the temperature zones where the deposits form appears to slightly spread out with the increase in contamination.

The main affect of the Brayco contamination on the VPC test is found in oil consumption, Figure 7. At all the contamination levels, the oil consumption is increased over the neat sample. One possible reason for the oil consumption increase is because of the increased volatility of the Brayco 599 product. If volatility was the entire reason for the increase in oil consumption the oil consumption should increase with the increase in Brayco contamination. The expected increase did not occur between the 1.25% and 7% levels. The reason for this might be because the variability in the 1.25% Brayco contamination oil consumption results. The two data points are quite far apart and therefore confidence in determining the oil consumption is limited.

The viscosity change, shown in Figure 7, does not appear to be significantly affected (within the repeatability of these tests) by the increase in Brayco contamination.

#### 4. Significance of the data.

a. The physical and chemical property test results for the Brayco 599 preservative additive blended at 1.25, 2.5, 5.0, 7.9 and 10% concentrations did not show significant changes in the properties measured compared to the untreated MIL-PRF-23699 CI lubricant. The moderate change in the deposit forming tendencies of the oil would become a problem if the engines were continually operated on the blended oil. Since this mix is used only for a short period of time the significance of the deposit forming tendency of the blend is greatly

minimized. However, the large drop in load carrying capacity of the 7% blend at higher concentrations is unsatisfactory.

b. The deleterious effects of the Brayco 599 product in MIL-PRF-23699 CI gas turbine engine oil at the 7% concentration on the Ryder Gear Load carrying capacity is the major concern. At low contact load conditions a product with 93% Herco A Ryder rating is not a serious problem. However, use of a lubricant with low Ryder Gear ratings increases the risk of developing unacceptable surface distress on gears and bearings when operated at moderate to high loads. The degree of surface damage will vary from minimal to heavy depending on the specific conditions of the contact surface being lubricated and is unique for every application. However, once initiated such distress can propagate leading to eventual component failure. Unlike the potential problem due to the increased deposition tendency of the 7% blend (where many hours of operation would be needed to form serious deposit levels) poor load carrying capacity can cause instantaneous surface distress on lubricated components under the proper conditions. While the amount of surface distress may be small, once formed it is a weak spot in the lubricated contact and can become an initiation site for more serious distress. The use of this mixture in the Navy F110 engines following rework places an increased risk on the lubricated parts and should be discontinued. The slight increase in corrosion resistance provided by the 7% blend (from 85% to 90% (for used oil)) is not justified by the 15% reduction in Ryder Gear load carrying capacity. The MIL-PRF-23699 CI oil alone provides sufficient corrosion protection without the added Brayco 599 and does so without compromising product performance.

## 5. Conclusions

a. The Ryder gear test results showed the 7% Brayco mixture to have significantly lower load carrying capacity than specification requirements. This can be detrimental to both gear and bearing systems in the form of increased wear and reduced life.

b. WAM testing indicates that the load capacity of MIL-PRF-23699 CI oil blended with 7% Brayco 599 has been compromised. Military engine operation with a lubricant having a similar WAM performance profile resulted in abnormal wear generation.

c. 4-Ball EP testing showed increased wear with the 7% Brayco concentration compared to the neat oil. This is indicated in the lower Load Wear Index obtained with the blended sample. This follows along with the Ryder gear test results

d. ALTE testing showed similar performance between both the neat CI oil and the 7% blend.

e. HTDT testing shows oil performance has been compromised with the larger doses of the Brayco additive. The results indicate potential oil deposition problems with the 7% and 10% Brayco 599 concentrations.

f. VPC testing produced a slight increase in oil consumption over the neat CI oil at all blend ratios. This is most likely due to the volatility of the Brayco at higher temperatures.

g. The basic physical properties of the blended sampled showed slight changes at higher concentrations of Brayco 599. The most significant change was elevated TAN, which should not be detrimental to the lube system.

h. The unused 7% Brayco blend showed similar corrosion protection when compared to the neat oil. Similar results were seen for the post-Oxidation/Corrosion test oil, although it is not clear if the Brayco 599 or the CI oil is providing the protection.

i. Oxidation/Corrosion testing showed a significant decrease in TAN at the end of the test, indicating that Brayco 599 is volatile at higher temperatures. Analytical testing performed to determine the remaining constituents in the sample was inconclusive.

j. Thermal Stability test results for the Brayco 599 blends were not substantially different than those of the neat CI oil. The decrease in viscosity is likely the result of the breakdown of the viscosity improver used in the Brayco 599.

## 6. Recommendations

a. It is recommended that the Brayco 599 product not be used in conjunction with MIL-PRF-23699 Class C/I oil in any US Navy application. MIL-PRF-23699 CI turbine oil was developed with specific additives used to inhibit corrosion in on lubricant wetted parts. The addition of Brayco 599 has demonstrated no benefit to the corrosion inhibiting properties of the oil. While the additive did not seem to adversely effect the thermal characteristics of the neat oil when used in a 7% concentration, other properties were effected. The decrease in the oil's load carrying capacity, as shown in Ryder and WAM results, is the most serious problem. MIL-PRF-23699 Class CI products have been specifically formulated to provide a balance between load carrying ability and corrosion protection. Using a product to boost corrosion protection throws off that balance, especially since it has not been shown to offer substantial improvements in corrosion protection. The problem with deposition is also a concern for continuous operation is not an issue for short green run operation.

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# Figure 1. Laboratory Test Results

	MIL-PRF-23699 C I Specification Limits	Production MIL-PRF-23699 C I	Brayco Concentration in MIL-PRF-23699 C I					Neat Brayco 599
			1.25%	2.50%	5.00%	7.00%	10%	
Viscosity, centistokes 40 C	23.0 at 40 C	25.72	25.8	25.97	26.24	26.46	26.8	41.1
TAN, mg/g KOH	1.0	0.63	0.92	1.19	1.74	2.19	2.88	25.2
Sediment, mg/L	10.0	3.1	2.1	1.6	1.6	0.9	1.6	6
Low Temperature Storage Stability No crystallization, gelling or separation	Pass	Pass	Pass	Pass	Pass	Pass	Pass	
Compatibility of Blends After 7 Days in the Oven at 200 F, mg/L		6	7.5	5	14.5	9	15	5.5
Elastomer Compatibility, % Swell AMS 3217/1, 72hrs @ 70 C AMS 3217/4, 72hrs @ 204 C	5-25 5-25	12.7 13.7				13.5 13.3	13.0 13.3	
Foam, Init. Vol-Final Vol, Time to Collapse Seq II Seq III	25-0, 1 minute 25-0, 1 minute	5-0 (0.03)* 5-0 (0.06)*					10-0 (0.05) 10-0 (0.21)	
Trace Metal, ppm								
Fe	2	0	0	1	1	1	1	11
Ag	1	0	0	0	0	0	0	0
Al	2	0	0	0	0	0	0	0
Cr	2	0	0	0	0	0	0	0
Cu	1	0	0	0	0	0	0	0
Mg	2	0	0	0	0	0	0	0
Na	Report	0	0	0	0	0	0	1
Ni	2	0	0	0	0	0	0	0
Pb	2	1	0	0	0	0	0	0
Si	10	0	0	0	0	2	0	0
Sn	11	4	6	4	4	4	3	4
Ti	2	0	0	0	0	0	0	0
Mo	3	0	0	0	0	0	0	0
Zn	2	1	0	0	0	1	0	1
P	No Limit Specified	1302	1381	1403	1438	1550	1538	2828
Oxidation/Corrosion, 72 hrs @ 204 C								
Viscosity Change, %	-5-25	15.44/15.09	15.89/15.04			14.51/14.29	14.33/13.88	
TAN Change, mg/g KOH	3.0	0.4/0.39	0.19/0.13			-1.03/-1.05	-1.60/-1.57	
Contamination, mg/100mL	50	2.0/1.58	4.0/3.37			4.0/4.74	14.32/6.74	
Weight Change, mg/cm <sup>2</sup>								
Steel	+0.2	-0.02/0.00	-0.04/0.00			0.01/-0.01	0.01/-0.01	
Silver	+0.2	-0.02/-0.03	-0.03/-0.01			-0.03/-0.02	-0.01/-0.03	
Aluminum	+0.2	0.00/0.00	0.00/-0.01			0.01/-0.01	0.01/-0.01	
Magnesium	+0.2	0.00/0.00	0.00/0.00			0.00/-0.01	0.00/-0.01	
Copper	+0.4	0.01/-0.03	-0.07/-0.07			-0.07/-0.09	-0.07/-0.10	
Thermal Stability/Corrosivity, 96hrs @ 274 C								
Viscosity Change, %	5.0 max.	-0.40/-0.43	-0.39/-0.43			-3.10/-3.51	-3.47/-3.25	
TAN Change, mg/g KOH	6.0 max.	1.73/1.59	1.49/0.89			1.09/1.06	0.96/0.75	
Metal Weight Change, mg/cm <sup>2</sup>	4.0	0.22/0.02	0.00/0.00			-0.01/-0.02	0.11/0.63	
Ball Corrosion Test								
New	75% Pass	80% *	100%			90% (light film)		
Post Oxidation/Corrosion Test	75% Pass	85% *				90%		
Ryder Gear Test, Relative %	102%	110% (DLA 1031)				93%		
Non-Specification Tests								
4-Ball EP Tests								
Load Wear Index		26.29/26.25	26.45/26.33				21.84/21.70	
Weld Point, kg		126/126	160/160				160/160	
4-Ball Wear Scar, mm								
10 kg		0.67	0.7	0.63	0.64	0.54	0.54	0.4
40 kg		0.89	0.75	0.83	0.8	0.77	0.8	0.9

\*Note: Results from original qualification sample

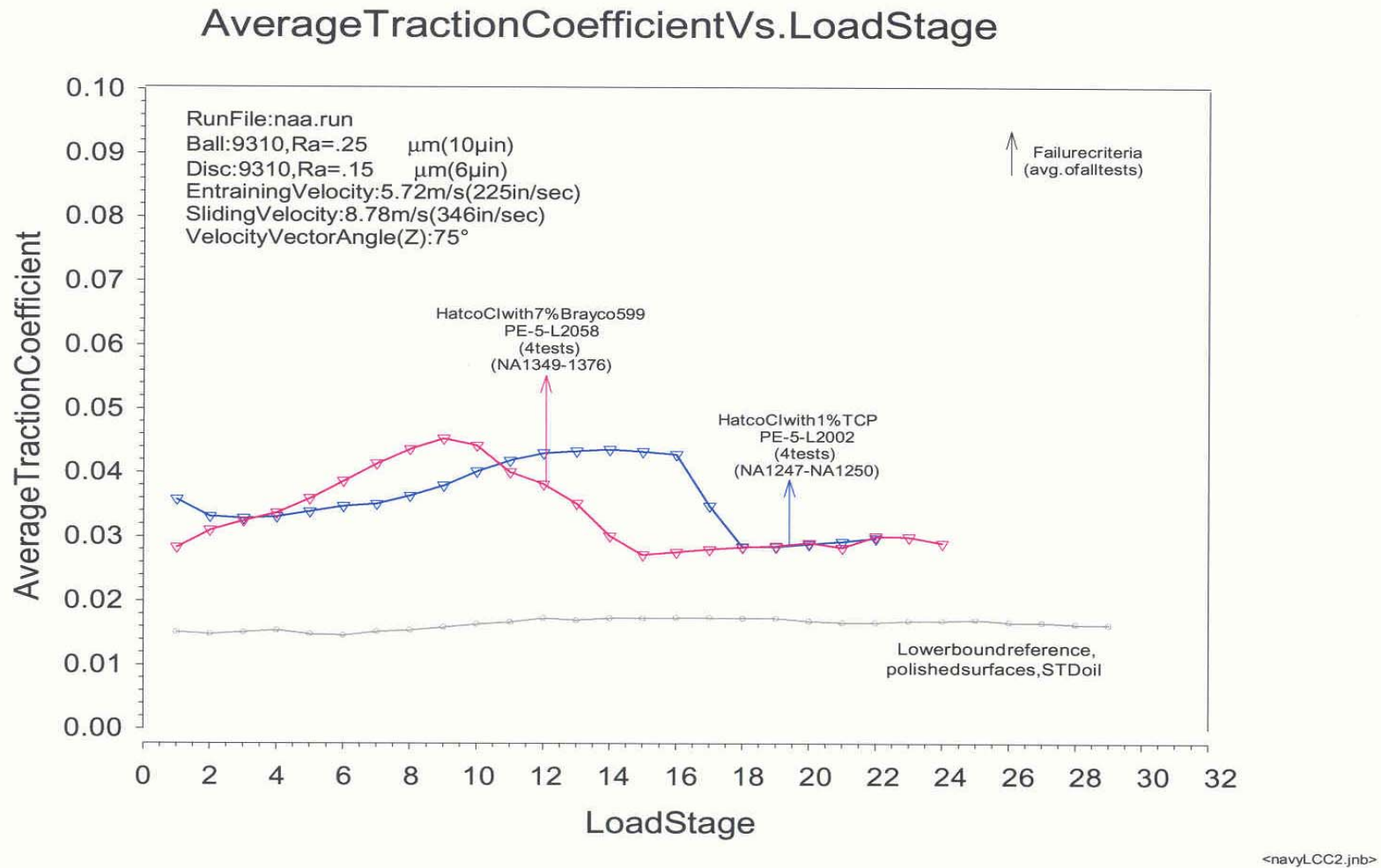
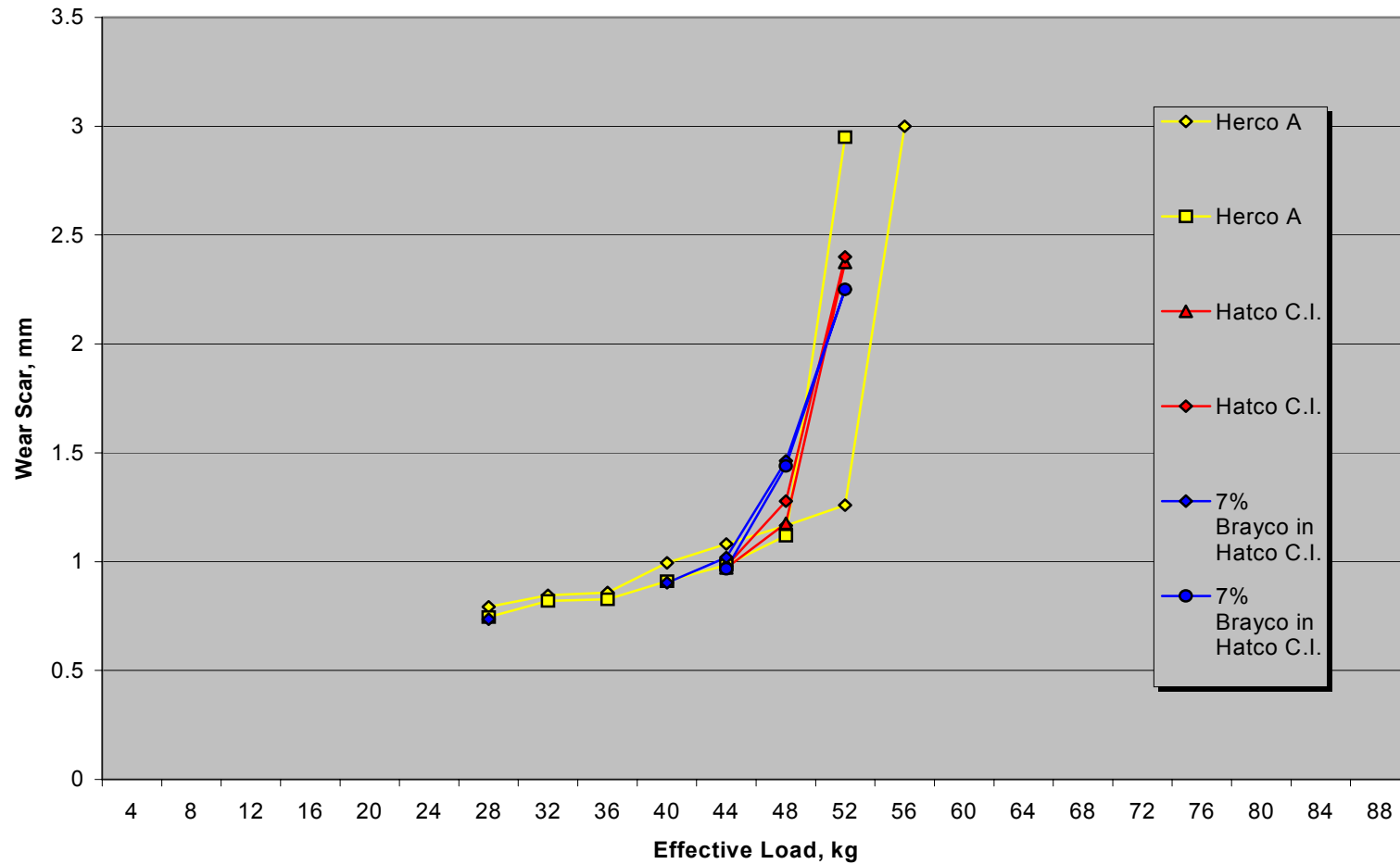


Figure 1. Traction Coefficient vs. Load Stage

**NAVY ALTE**  
**Scuffing Wear Test - C.I. Oil Vs. Brayco 599 Contamination**  
**1 minute @ 150C @ 220 rpm**

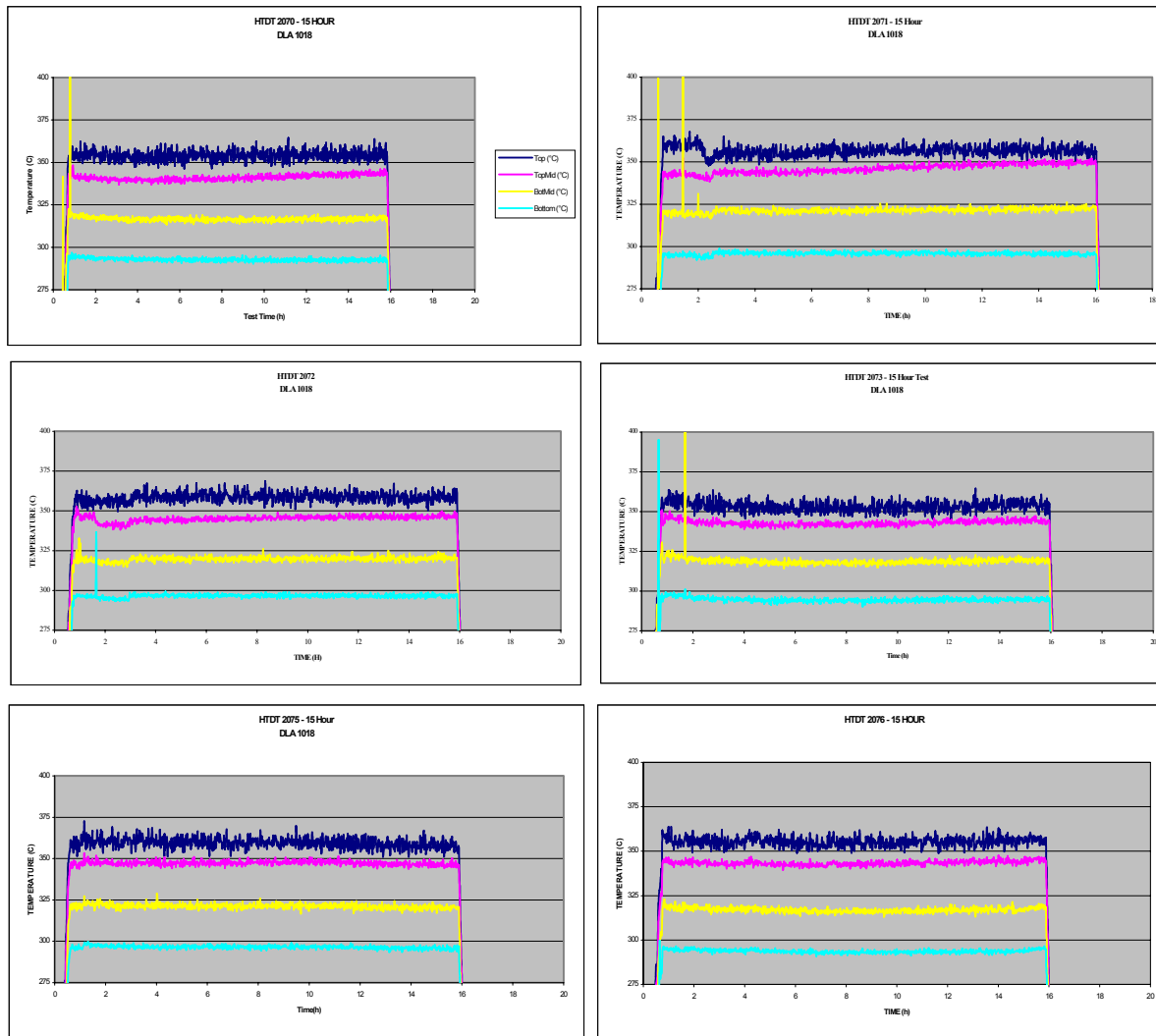


**Figure 2. ALTE Scuffing Wear Test**

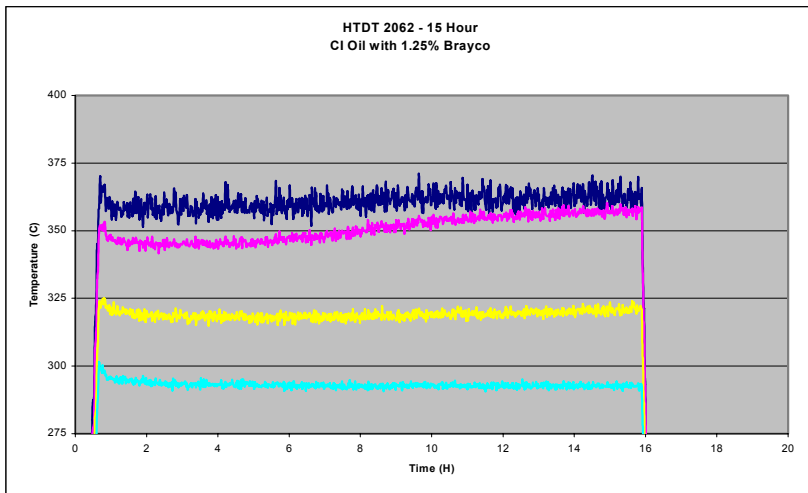
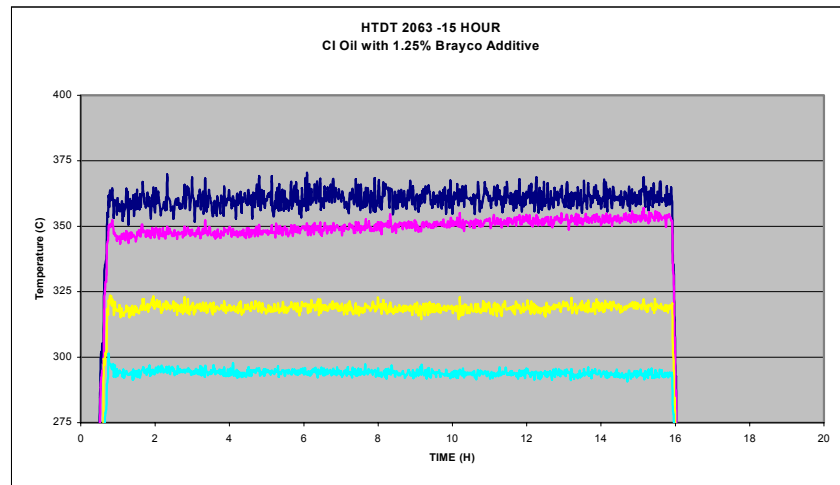
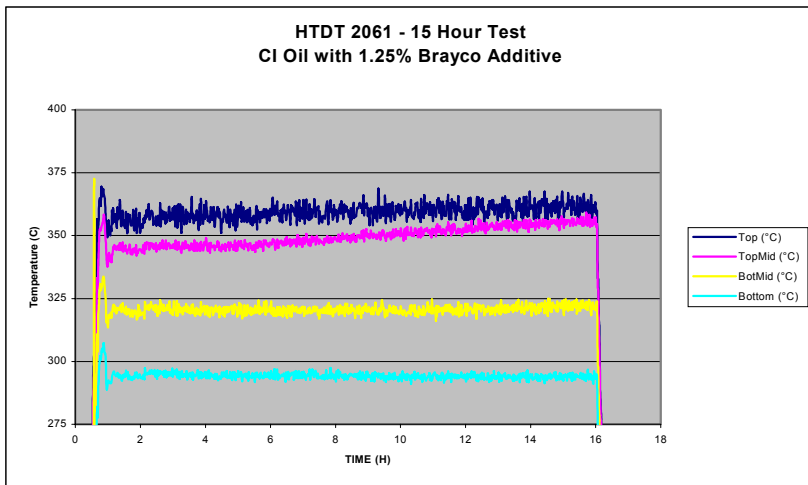
**Table 2. HTDT Test Results**

High Temperature Deposition Test Conditions:  
Upper Tube Temperature = 357°C, Oil In Temperature = 163°C, Cabinet Temperature = 93°C,  
Oil Flow = 300 ml/min., Saturated Air Flow = 1000 ml/min., Tot

<i>Test No.</i>	<i>Oil Code #</i>	<i>Manf. Name</i>	<b>Tube Deposit Weight (mg)</b>	<b>Deposit Type Rating</b>	<b>% Viscosity Change</b>	<b>TAN Change (mg KOH/g)</b>	<b>Oil Consumption (ml)</b>	<b>Date</b>	<b>Test Method</b>
2070	DLA1018	CI Oil	12	4.2	10.8%	0.08	65	08/10/00	15 hour test
2071	DLA1018	CI Oil	13	3.6	9.3%	0.22	30	08/14/00	15 hour test
2072	DLA1018	CI Oil	12	2.2	18.5%	0.33	135	08/15/00	15 hour test
2073	DLA1018	CI Oil	7	3	9.4%	0.22	40	08/16/00	15 hour test
2075	DLA1018	CI Oil	8	2.8	9.7%	0.29	40	08/21/00	15 hour test
2076	DLA1018	CI Oil	7	2.7	8.8%	0.16	40	08/22/00	15 hour test
2061	2047	1.25% Brayco	12	5	10.2%	-0.30	25	07/27/00	15 hour test
2062	2047	1.25% Brayco	10	4.2	13.4%	-0.26	70	07/31/00	15 hour test
2063	2047	1.25% Brayco	11	4.2	9.9%	-0.28	35	08/01/00	15 hour test
2064	2048	7% Brayco	68	5.8	37.2%	1.00	80	08/02/00	15 hour test
2065	2048	7% Brayco	16	4.6	9.7%	-1.33	35	08/07/00	15 hour test
2066	2048	7% Brayco	56	5	36.1%	0.74	85	08/08/00	15 hour test
2067	2049	10% Brayco	106	6.6	43.7%	1.09	83	08/09/00	15 hour test



**Figure 3. CI Oil without Brayco 599 Additive**



**Figure 4. CI Oil with 1.25% Brayco 599 Additive**

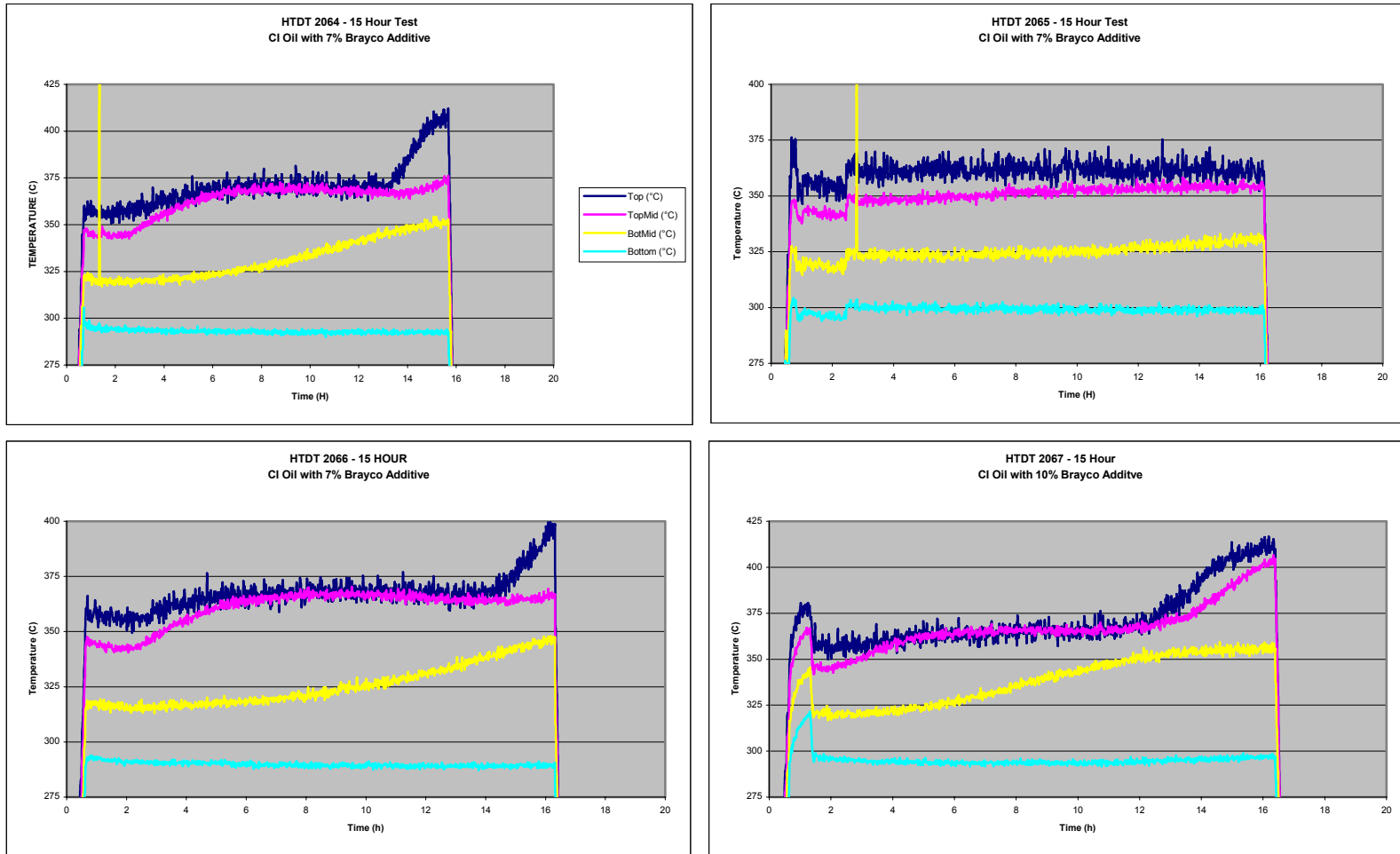
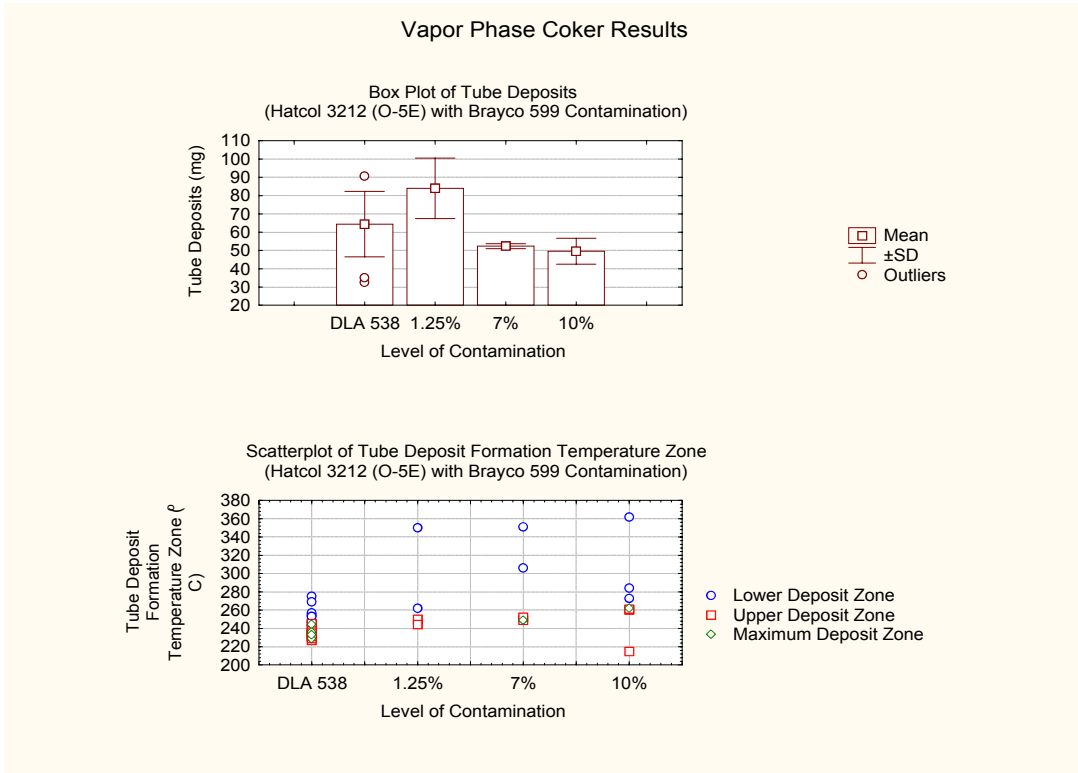
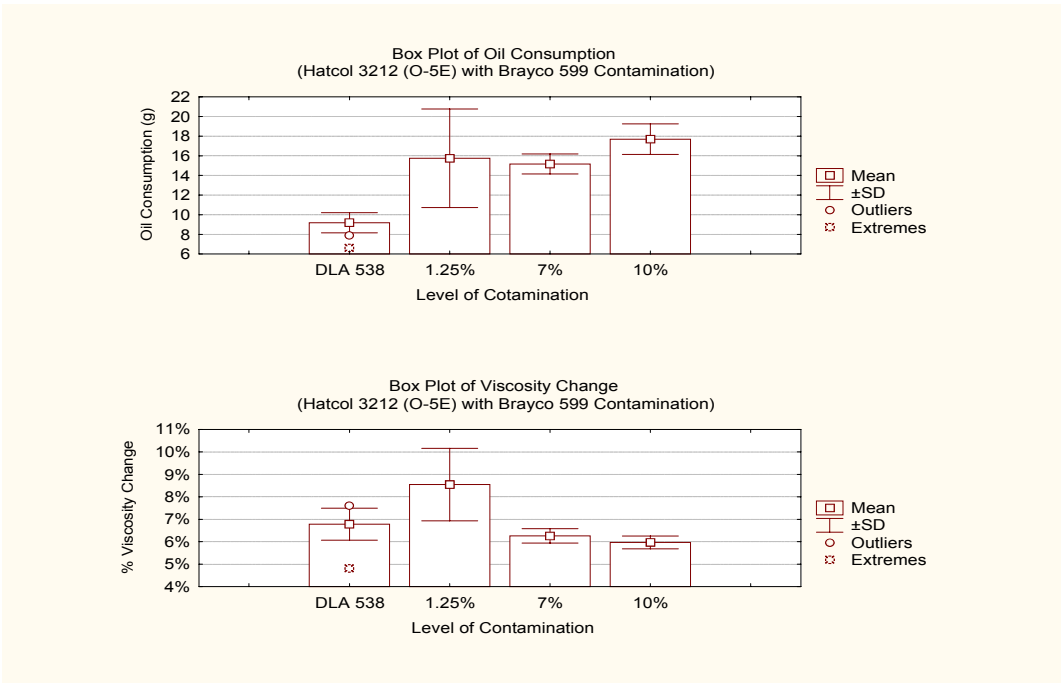


Figure 5. CI Oil with 7% Brayco 599 Additive



**Figure 6. Tube Deposits and Deposit Formation**



**Figure 7. Oil Consumption and Viscosity Change**

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